Section I: Multiple Choice

Listed below are the correct answers to the multiple-choice questions and the percentage of AP candidates who answered each question correctly.

Section I Answer Key and Percent Answering Correctly

Item No.	Correct Answer	Percent Correct by Grade 5	4	3	2	1	Total
1	E	95	87	82	71	52	80
2	A	97	93	87	79	61	86
3	B	93	88	80	71	49	78
4	C	98	96	94	91	81	94
5	B	99	98	93	84	58	89
6	E	88	82	77	72	57	77
7	D	99	96	91	80	56	86
8	E	83	70	63	58	50	66
9	A	68	50	40	37	41	48
10	E	70	56	46	32	17	48
11	B	89	82	74	66	54	74
12	D	89	75	62	45	21	61
13	A	88	76	64	51	32	64
14	E	89	74	60	41	25	61
15	B	78	58	36	21	13	44
16	A	91	82	69	52	34	68
17	A	96	87	72	56	38	73
18	D	59	44	39	35	30	42
19	B	61	44	37	34	30	42
20	D	87	71	55	42	25	57
21	C	86	71	54	34	17	56
22	A	92	82	69	54	29	69
23	C	86	71	58	44	30	60
24	A	79	64	56	44	25	57
25	C	63	46	38	30	23	41
26	B	87	74	60	46	32	62
27	C	98	98	97	94	83	95
28	D	71	60	50	43	30	51
29	A	93	84	77	66	48	75
30	E	77	66	56	40	18	54
31	B	88	75	63	46	28	62
32	D	69	56	42	29	23	46
33	E	74	51	31	16	11	37
34	D	79	60	43	31	17	48
35	B	65	43	30	24	13	36
36	D	48	32	22	15	12	27
37	B	72	52	34	24	18	43
38	D	58	38	29	23	20	33
39	E	94	86	74	57	31	71
40	D	40	18	13	14	16	20
41	B	64	36	23	16	14	33
42	C	82	62	45	30	20	51
43	E	86	70	53	38	26	55
44	B	76	60	49	43	44	56
45	D	85	70	54	43	26	59
46	B	82	66	53	36	22	53
47	B	50	25	15	14	18	24
48	B	91	74	55	37	23	58
49	E	67	53	46	37	24	47
50	A	44	22	12	10	8	20
51	A	59	41	32	19	10	33
52	A	90	79	67	53	36	67
53	C	72	61	55	47	31	54
54	E	88	75	63	50	26	63
55	D	29	23	22	18	11	22
56	D	62	47	37	29	19	40
57	E	45	25	16	12	9	22
58	D	38	26	25	25	23	27
59	B	79	64	53	40	28	54
60	C	41	25	23	17	12	23

Item No.*	Correct Answer	Percent Correct by Grade 5	4	3	2	1	Total
61	B	67	48	41	36	34	46
63	C	86	67	46	36	28	53
64	B	67	49	35	25	15	40
65	B	80	60	42	26	19	47
66	D	87	69	52	35	20	55
67	E	86	65	46	31	18	51
68	E	82	56	37	24	18	45
69	D	69	50	34	22	14	39
70	A	92	79	61	41	22	62
71	E	95	88	79	69	55	79
72	B	100	99	98	96	87	97
73	C	74	56	42	32	26	48
74	E	86	78	71	65	48	71
75	A	83	73	65	61	53	69
76	D	71	64	57	48	37	57
77	C	92	82	75	65	43	73
78	E	77	61	51	42	28	53
79	A	84	75	67	58	42	67
80	B	99	98	96	92	82	95
81	D	85	74	69	58	43	67
82	D	75	57	47	38	23	49
83	B	87	65	47	31	21	53
84	C	86	60	36	23	16	46
85	E	90	72	52	38	22	57
86	A	94	82	71	60	43	72
87	E	77	57	47	37	26	51
88	C	94	83	73	61	41	72
89	E	41	26	22	16	17	24
90	D	62	43	32	23	16	38
91	A	81	64	55	40	25	55
92	B	93	74	53	33	21	57
93	C	95	79	57	38	24	61
94	E	94	81	58	43	27	62
95	A	91	75	57	41	25	60
96	E	91	71	43	22	10	49
97	B	90	75	54	34	18	56
98	B	86	68	42	24	17	49
99	B	89	67	41	22	19	48
100	A	62	41	32	24	19	36
101	C	53	36	28	21	17	32
102	D	89	80	71	60	44	70
103	B	86	70	56	37	25	58
104	A	98	96	94	89	69	91
105	C	64	55	46	40	27	48
106	E	89	87	85	82	64	82
107	B	95	89	84	78	60	83
108	D	63	50	42	34	24	44
109	A	79	66	57	49	38	59
110	D	92	86	80	72	48	78
111	C	84	70	54	36	18	55
112	D	86	74	57	36	18	57
113	B	58	42	30	22	18	36
114	B	98	94	89	76	45	84
115	A	67	58	46	34	22	47
116	A	91	75	61	40	23	61
117	B	92	84	80	63	43	75
118	E	64	53	43	37	28	47
119	D	93	85	76	61	35	73
120	A	61	54	51	50	43	53

*Item No. 62 was not scored.

Scoring Guidelines and Sample Student Responses

The answers presented here are actual student responses to the four free-response questions on the 1999 AP Biology Examination. The students gave permission to have their work reproduced at the time they took the exam. These responses were read and scored by the leaders and faculty consultants assigned to each particular question during the AP Reading in June 1999. The actual scores that these students received, as well as a brief explanation of why, are indicated.

Describe, Explain, Design — these are the important directives that appear in each of the four FR questions on this year's examination. The questions required students to exhibit higher order thinking skills—not simply learning and feeding back a collection of facts.

- Question 1 is a laboratory/experimental question on photosynthesis that asks students to design an experiment.
- Question 2 is a broad, comprehensive question on the biology of cell-to-cell communication.
- Question 3 is based on analysis of a biological classification scheme, and is basically an evolution and systematic biology question.
- Question 4 deals with how DNA meets the criteria for being hereditary material and asks students to describe experimental evidence supporting one of the criteria.

These four questions covered the breadth of what is typically covered in a two-semester college-level biology course. All four had multiple parts, and there were many ways that students could get full or partial credit. This was an extremely challenging set of FR questions. The diversity of biological facts, mechanisms, and theories was well represented on these exam topics.

Question 1 Scoring Guidelines

Question 1 is the laboratory question for 1999; it focuses on **designing** an experiment to test the effects of one of three possible environmental variables on the rate of photosynthesis. After designing the experiment, students are asked to **explain** how they would measure photosynthetic rate in their experiment. The third part of the question asks students to **describe and explain** their expected results. Designing an experiment is not a new task on a free-response question, and the three-part design of the question is typical of such questions in recent AP Biology Exams. The standards were set in such a way that students could garner 7 points for experimental design, 2 points for describing expected results, and 3 points for biological explanation of results. Our typical scoring requires students to get points from all parts of a multipart question before achieving a maximum score of 10.

A. **Experimental Design:** (7 points maximum)

The following experimental characteristics may earn 1 point each:

*Score only the **first** independent variable (temperature, λ, intensity) manipulated, and the **first** factor used by the student to measure photosynthetic rate (O_2, CO_2, etc.).*

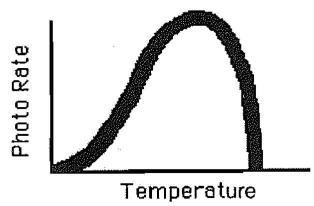
A 3-point maximum in Section A if the experiment will not work biologically. Examples: using an organism that is not photosynthetic, or using an apparatus that biologically will not measure photosynthesis as designed (i.e. potometer or respirometer). 0 points lost for a minor flaw in technical design.

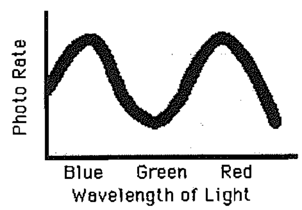
- State **hypothesis** (clear statement of a hypothesis, identifies it as a hypothesis, uses "If/then" statement
- Specify a **control group** for comparison
- Identify and **hold constant at least one experimental factor** that can affect photosynthetic rate
- Manipulate **the independent variable** (change the temperature, λ of light, intensity of light)
- Describe **what is being measured** to determine rate (CO_2 or H_2O consumption, O_2 or carbohydrate production, growth, e^- flow measured with dye reduction, production of an intermediate product, etc.)
- **Quantify** the measurement of the variable (method **and** time frame of measurement)
- Rate calculation or definition
- Verify results through sample size (>1) or repetition
- Utilize **statistical application** of data (mean, t-test, ANOVA, etc.)
- Design an **exemplary** experiment

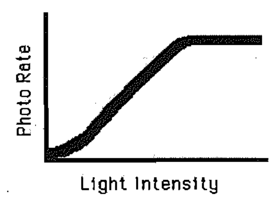
B. **Describe expected experimental results** (2 points maximum)

- Verbal or graphic description of expected experimental results (1 point)
- Verbal or graphic description of expected results across the entire range of biological activity (1 point)
- The graphs below represent 2-point graphs, but to earn **any** points, graphs must be accurately labeled

Temperature	**Wavelength**	**Intensity**
• Rate rises with temperature to an optimum and then falls	• An "action spectrum" with highest rates in the blue and red regions of the spectrum	• Rate increases steadily to a maximum and levels off







How students could earn points in this section:

- One point for a reasonable **description of expected results** from experimental set-up, and a second point if description included what to expect if the independent variable extended across the range of biological activity.
- To earn points for **temperature results,** a photosynthetic rate that rose with temperature to an optimum and then fell. A description or a graph similar to the one in the table above could earn the student 2 points.
- To earn points for **wavelength results,** a photosynthetic rate showing an "action spectrum" with highest rates in the blue and red regions of the spectrum and a pronounced dip in the green. A description or a graph similar to the one in the table above could earn the student 2 points.
- To earn points for **light intensity results,** a photosynthetic rate that rose with temperature to an optimum and then leveled off. A description or a graph similar to the one in the table above could earn the student 2 points.

C. **Biological explanation of results** (3 points maximum)

- **Temperature**
  - Enzyme kinetics or metabolic changes
  - Enzyme denatures
  - Photorespiration
  - Stomatal closing with high temperature, limits CO_2, and lowers rate
  - Excessive water loss, less reactant available for reaction
  - Elaboration

- **Wavelength**
  - Absorption/reflection of light by chlorophyll
  - Accessory pigments absorbing green light
  - Relation between wavelength and energy
  - Elaboration
- **Intensity**
  - More photons hit photosystems
  - More e^- flow in the electron transport system/time
  - Plateau caused by limiting factors
  - Elaboration

How students could earn points in this section:

- In this section, students could earn points by giving solid, biological explanations for the changes in photosynthetic rates they would expect.
- The simplest way to earn 2 points was by explaining both the rise and fall of the temperature curve, both "peaks" and the "valley" of the action spectrum, and both the rise and the plateau of the light intensity curve.
- There was also an elaboration point to be given at the readers' discretion for very strong, in-depth answers.
- Answers were expected to contain some sophistication, and answers such as, "In the high temperature, the plant dies so photosynthesis is lower" or "Since light is important to photosynthesis, with higher intensities, photosynthesis goes faster," did not receive points.

Essay 2 (8 points)

Using sweet pea plants, my experiment would test the ~~wh~~ effects of temperature upon the rate of photosynthesis. My hypothesis would be that if ~~a~~ the sweet pea plant grows well in mild, warm conditions, then extremeties such as harsh cold or scolding heat will most likely ~~stop~~ hinder growth or even kill the plant. I chose sweet pea plants because of their common variety, and ~~a~~ fast rate of growth. Photosynthesis, or the rate thereof, would be measured by the growth of the plant over a period of time, given that in optimal conditions, sweet pea plants grow ~~[illegible]~~ rapidly.

My experiment would consist of 10 plants, grown from seeds, at each ten point mark on a Fahrenheit thermometer. Therefore, there would be ten test subjects at 30°, ten at 40°, ten at 50°, ten at 60°, ten at 70°, ten at 80°, ten at 90°, ten at 100°, and ten at 110°. At room temperature, 75°F, I would have ten control subjects. Using growth chambers, all plants would receive the same amount of humidity, sunlight, water and soil, with the only variance being temperature in each growth chamber. Each chamber would be set to shed ~~10~~ hours of sunlight upon each plant, much like a common summer day in the temperate zone. Each test subject would be measured in height and observed for heartiness and color on a day to day basis.

My predictions would be that in the growth chambers ~~be~~ set below 60°F, there would be virtually no plant growth. In the chambers set from 60°F to 90°F, maximum growth would be observed. In the control chamber of 75°F, average ~~[illegible]~~

optimal growth would be displayed, and in the growth chambers of 100° and 110°, a decline in growth would be demonstrated. I would expect these results because just as cold temperature may inhibit photosynthesis, and slow down levels of cell reproduction, warmer temperatures may be to harsh for the plant, stripping it of vital water through evaporation.

Commentary on Essay 2

In Part A, points were earned for stating a **hypothesis,** identifying **what** dependent variable is to be measured (growth), **verifying** the results by using 10 plants in each experimental condition, **manipulating** the independent variable (temperature), **eliminating** other variables ("same amount of humidity, sunlight, water and soil"), and for **quantifying** *how* (measuring height) and *when* ("day to day") the dependent variable would be measured. In Part B, 2 points were earned for describing expected results **across the range** of biological activity.

Essay 3 (10 points)

The experiment would test ~~the effect~~ how varying wavelengths of light affect the rate of photosynthesis in a young maple tree. ~~I hypothesize~~ Four young plants would be used, each placed in a glass tank in a black closet. Each closet would have a ventilation system that maintains an air content of 79% nitrogen, 20% oxygen, and ~~[illegible]~~ 1% carbon dioxide. The first maple tree (young, so that it would be small and able to fit in the tank that contains ~~dirt~~ soil and is open to the air of the closet) would be a control exposed to visible light from ~~a~~ a lamp positioned one foot above the plant. The lamp would simulate the sun, giving off a full spectrum of wavelengths of light. The second tree would be exposed to red light, set up like the control. The third would be exposed to blue light, and the forth to green light.

These light wavelengths represent the two ends of the visible light spectrum, while green has a wavelength in between the wavelengths of red (longest) and blue (shortest) (~~along with the~~ except violent). My first hypothesis would be that the ~~trees exposed to blue light would~~ tree exposed to blue light would have a higher rate of photosynthesis than the tree exposed to red light. My second hypothesis would be that the tree exposed to green light would have the lowest rate of photosynthesis. My third hypothesis would be that the control exposed to "sunlight" would have the highest rate. Thus, the variable of my experiment would be the wavelength of light.

Each tree would be exposed to its respective light source for three weeks. After this time period, each plant would be ground up and tested for starch content, since photosynthesis produces carbohydrates stored as starch, mostly in the roots but also in the leaves themselves. A simple test could be to use iodine, which detects the presence of starch, although it is likely that all four plants would contain some starch. ~~If the~~ To really ~~find the~~ measure the rate of photosynthesis, the specific number of grams of starch should be found by analyzing the plant content. ~~Before beginning the~~

I would expect the tree exposed to the full spectrum of light to have the highest rate of photosynthesis because the light-absorbing pigments in a plant chloroplast differ in which wavelengths of light they absorb. Chloroplyll a absorbs light of

wavelength 700 and 680 nm, while other pigments like chlorophyll b absorb light of different wavelengths to use as energy for photosynthesis. Either the red or blue-light exposed tree would have the next highest starch content because chlorophyll tends to have the highest absorption of light of these wavelengths. Finally, I would expect the tree exposed to green light to wither and die because chlorophyll, a green pigment, reflects green light rather than absorbs it. The energy is not taken in, so this tree cannot ~~per~~ carry out photosynthesis. It would have the lowest starch content of the four plants. The overall order, from highest to lowest, of photosynthesis rates would be: control, red or blue, green. This experiment should be repeated numerous times - at least 50 - to prove its validity. Though maple trees are apt specimens because of their broad leaves and tap roots, the experiment should be tried with maple seeds from the beginning as well as starting with young plants.

Commentary on Essay 3

In Part A, points were earned for, **eliminating** other variables by keeping gas concentrations constant, identifying a **control** group for comparison, stating a **hypothesis, manipulating** the independent variable (starch content), for **quantifying** *how* (measuring the grams of starch) and *when* ("over three weeks") the dependent variable would be measured, and **verifying** the results by repeating the procedure. In Part B, 1 point was earned for describing expected **results** in a limited way (full spectrum sunlight with the highest rate), and 1 point for describing expected results **across the range** of the light spectrum. In Part C, a point was earned for a good **explanation** of light absorption and reflection by chlorophyll.

Common Errors and Misconceptions

Part A

- Most students failed to earn the "Quantify" point because they did not explain how to measure gases like oxygen and carbon dioxide; when they did, they failed to describe the time frame in which the gases would be measured.
- Few students earned points for a rate calculation/definition, using a statistical application, or designing an exemplary experiment.
- Students often used equipment from other AP Laboratory protocols such as potometers and respirometers.
- A widely held misconception is that transpiration rate equals photosynthetic rate.
- Another misconception is that light duration and light intensity are the same.
- Many students who sought to measure plant growth and used darkness as a control or simply a light intensity treatment failed to realize that plants can grow vigorously in the dark.
- Often students chose to measure photosynthetic rate by examining the "health" of the plant.

Part B

- Most students seemed unaware of the temperature curve going down and the light intensity curve leveling off at higher temperatures.

Part C

- Generally, students garnered few points in this section, which relied almost entirely on basic AP-level biological knowledge.
- Students had difficulty explaining results, especially when they tried to relate reaction rate to the events in the "light phase" of photosynthesis. They seemed to do a little better relating the lowered kinetic energy of reactants at low temperature and the denaturing of enzymes at higher temperature.
- Very few student essays combined strong experimental designs with an in-depth knowledge of photosynthesis.

Question 2 is a four-part question about different kinds of communications between cells in multicellular organisms. Students are expected to write on three categories, **describing** the communications that occurs. One choice is communication between plant cells, and the other three choices involve communication between cells found in animals. For one of these, students have the option of choosing between neuron-to-neuron and neuron-to-muscle-cell communication.

For scoring student essays, a simple template for determining the distribution of points was developed, along with a ten-page addendum covering the details of plant cell communication, immune system cell communication, neuron-to-neuron/neuron-to-muscle-cell communication, and specific endocrine gland-to-target-cell communications. The complexity inherent in the immune system and the endocrine system necessitated these extremely detailed and lengthy standards. This broad question gave students an opportunity to demonstrate factual knowledge gained during their AP Biology course, while allowing students to choose the type of cell communication with which they were most familiar.

Students could earn a maximum of 4 points within a category. This ensured that three categories must be addressed in order for the student to be able to earn a grade of ten for this essay. The 4 points were distributed as follows:

- one (1) point maximum for describing the **source** cell
- one (1) point maximum for describing the **signal**
- two (2) points maximum for describing **responses** elicited

These latter 2 points could be earned by describing two different responses (2 response points), or by describing 1 response in detail (1 response point and 1 elaboration point). Elaboration points could not be earned for describing source or signal, except as noted in the guidelines.

Template for Determining the Distribution of Points

	Source [1 point maximum]	**Signal** [1 point maximum]	**Responses/Elaborations** [2 points maximum]
Communication between two plant cells [4 points maximum]	Hormone-producing cell (generic)	A specific plant hormone	Various physiological changes
	Plasmodesmata (elaboration point for good description)		Ion movement; H_2O movement; RNA movement

How students could earn points in this section:

Plant Hormonal Communication

- **Source point** could be earned by a phrase such as "hormone-releasing cell." This is due to the fact that plant hormones are often produced in multiple locations, e.g., various meristems.
- **Signal point** could be earned only by naming a specific plant hormone (auxin, gibberellin, etc.).
- **Response point(s)** could be earned by naming any of the general or specific effects associated with the hormone chosen.

Plant Non-Hormonal Communication

- **Source point** could be earned by a description of a plasmodesma.
- **Source-elaboration point** could be earned by a more detailed description of such; no points were earned for simple use of the term plasmodesma without an accompanying description.
- **Response point(s)** could be earned by identifying specific responses that result from communication via plasmodesmata.

The standards also incorporated opportunities for earning points for such examples as phytochrome-mediated communication, communication involved in touch-sensitive plants, etc.

Communication between two immune system cells [4 points maximum]	Any two immune system cells interacting or An immune system cell interacting with the product of another immune system cell	T_C/APC docking Antibody Histamine Interferon	Discharge of perforin; phagocytosis of pathogen; inflammatory response; phagocyte activation; Ab secretion; clonal selection

How students could earn points in this section:

Typically, two immune-system cells will initially interact (e.g., T_H docking with an APC), setting off a sequence of events involving an early release of lymphokines/interleukins that elicit multiple effects such as activation of other immune-system cells. In turn, one of the initial cells may subsequently interact with a different type of immune-system cell (e.g., T_H docking with a B cell, for a T-dependent antigen), mediating release of additional lymphokines/ interleukins that elicit still other effects. And so, there are initial sources/signals/responses, intermediate sources/ signals/responses, and late-term sources/signals/responses.

A student could earn points by starting anywhere in the sequence and describing the interaction of any immune-system cell with another immune-system cell.

The definition of what constitutes an immune-system cell is not static. For example, an uninfected epithelial cell would not be considered an immune system cell, whereas that same cell infected by a virus would be considered an immune system cell, given that it releases interferons, one of whose effects is to activate phagocytes. Interactions between an immune-system cell and the products of another immune-system cell (e.g., the phagocytosis by a macrophage of an Ab-bound pathogen) also fell within the parameters of the question.

Communication between two neurons **OR**	Sending neuron	Neurotransmitter	Chemical gating; depolarization of postsynaptic membrane; EPSP, IPSP, or both
between a neuron and a muscle cell [4 points maximum]	Sending neuron	Neurotransmitter	Action potential to T tubules; Ca^{++} release from sarcoplasmic reticulum; Ca^{++} binding to troponin; cross-bridge formation

How students could earn points in this section:

Neuron-to-Neuron Communication

- source point for a description of a sending neuron, i.e., one involved in transmitting a signal across a chemical or electrical synapse.
- signal point for describing a generic neurotransmitter (in the case of chemical synapses) or for describing direct current flow (in the case of electrical synapses utilizing a gap junction).
- response points, any of the various effects elicited in the post-synaptic neuron could earn up to 2 points.

Neuron-to-Muscle-Cell Communication

- The criteria of a sending neuron and a neurotransmitter were the same as described for neuron-to-neuron communication.

- Up to 2 response points for any of the various effects elicited in the muscle fiber, whether initial, intermediate, or late-term. It should be noted that most students, in designating a muscle fiber, did not specify skeletal, cardiac, or smooth muscle; the standards attempt to encompass all of these.

Communication between a specific endocrine-gland cell and its target cell [4 points maximum]	Specific gland (elaboration point for peptide vs. steroid hormone pathways)	Specific hormone	Specific effect

How students could earn points in this section:

The precise wording of the question required specificity and linkage for the answer to earn points.

- A **signal** point could not be earned in the absence of a **source point** or a **response** point. Thus, a student who described an endocrine gland as releasing a mismatched hormone (e.g., pituitary → aldosterone) earned nothing; whereas a student who described an endocrine gland with its correctly matched hormone (e.g., pineal gland → melatonin) earned two points, i.e., for source and signal. Likewise, a hormone had to be linked to responses it actually elicits to earn response points. Points could be earned for initial, intermediate, or long-term responses.
- It was also possible to earn a source point and response points by correct linkage, even in the absence of a signal point (e.g., the pituitary causing ovarian follicle growth without mention of FSH).
- Correct linkage between source–signal–responses was necessary for a student to earn four points in this category.
- Points were awarded if a student designated "the pituitary" as the source for FSH or prolactin, without designating the anterior lobe specifically. Likewise for "the adrenal" as the source of hormones from the adrenal medulla and the adrenal cortex. However, if a student attributed a hormone of the adrenal medulla to the adrenal cortex, no points were earned.
- Although many non-steroid hormones may eventually be found to involve a signal transduction pathway that includes a second messenger, a point was awarded only for those hormones that have been identified as having such a second messenger in the textbooks and reference works available to the readers.
- In addition, a student could earn up to 4 points for an accurate description and linkage of an endocrine gland, hormone, and responses from an invertebrate, although such answers were very rare.

Addendum: Details of Communications between Cells in Multicellular Organisms

Part I – Plant cell-to-plant cell communication
Plant hormonal communication

Source:	**Signal:**	**Response/Recipient Cell:**
Apical bud/young leaves	**Auxin (IAA)**	▪ cell elongation ▪ increase in cell wall plasticity ▪ stimulation of proton pumps/lowering of cellular pH ▪ stem elongation ▪ root growth/differentiation ▪ stem phototropism (+), root phototropism (–) ▪ stem gravitropism (–), root gravitropism (+) ▪ suppression of lateral buds (apical dominance) ▪ organogenesis
Seed	**Auxin (IAA)**	▪ cell elongation ▪ seed germination ▪ fruit development

Source:	Signal:	Response/Recipient Cell:
Root cells	**Cytokinin**	▪ root growth/differentiation ▪ cell division (general effect) ▪ delay of senescence (particularly in leaves) ▪ organogenesis
Seed hypocotyl	**Cytokinin**	▪ cell division (general effect) ▪ seed germination
Source:	**Signal:**	**Response/Recipient Cell:**
Apical bud meristem Root meristem Young leaves	**Gibberellins**	▪ bud growth (including breaking of lateral bud suppression) ▪ stem elongation ▪ root growth ▪ root differentiation ▪ leaf growth ▪ flowering ▪ bolting ▪ fruit development
Seed embryo	**Gibberellins**	▪ stimulation of aleurone cells to release hydrolytic enzymes ▪ endosperm breakdown ▪ seed germination
Older tissue Water-stressed tissue Unripe fruits	**Abscisic acid**	▪ growth inhibition ▪ closing of stomata ▪ reinforcement of seed dormancy ▪ stress responses
Ripening fruits Stems Older leaves Flowers	**Ethylene**	▪ promotion of fruit ripening (autocatalytic) ▪ hypocotyl hook formation ▪ inhibition of cell elongation ▪ root growth/inhibition (dose- and species-dependent) ▪ leaf growth/inhibition (dose- and species-dependent) ▪ flower growth/inhibition (dose- and species-dependent) ▪ leaf abscission
Wounded tissue Infected tissue	**Ethylene**	▪ stimulation of suberin deposition (physical barrier to pathogens) ▪ stimulation of phytoalexin biosynthesis (chemical barrier to pathogens) ▪ potentiation of hypersensitive response

Note: A description of phytochrome-mediated responses (e.g., flowering, etc.) can also earn up to 4 points in this category.

Plant non-hormonal communication

Source:	Signal:	Response/Recipient Cell:
Plasmodesmata (elaboration point for good description)		▪ water movement ▪ ion movement ▪ movement of informational molecules, e.g., RNA
Mimosa leaves/pulvini Venus flytrap sensory hairs	**K^+ movement**	▪ loss of turgor ▪ propagation of action potentials in plant

Addendum, *continued*

Part II – Immune-system-cell to immune-system-cell communication

Interferon release by virus-infected cells (infected cell becomes immune system cell)

Source:	Signal:	Response/Recipient Cell:
Virus-infected cells	**Interferon**	■ activation of phagocytes ■ resulting ingestion of microbes

Cytotoxic T cell (T_C) "docking with" antigen-presenting cell (APC = cell infected with intracellular pathogen or a cancer cell)

Source:	Signal:	Response/Recipient Cell:
APC	**T_C/APC docking**	■ discharge of perforin by T_C ■ pore formation in cell membrane of infected cell ■ cell lysis

Helper T cell (T_H) "docking with" antigen-presenting cell (APC = macrophage)

APC	**T_H/APC docking**	■ release of IL-1/cytokines by APC ■ T_H activation ■ release of IL-2/cytokines by T_H cell ■ T_H proliferation (mediated by IL-2)* ■ formation of memory T_H clone (mediated by IL-2)* ■ T_C activation (med. by IL-2; CMI) ■ B cell activation (mediated by IL-2; AMI/humoral immunity) ■ "docking" of T_H with a B cell (for T-dependent Ag) ■ formation of plasma B cell clone* ■ formation of memory B cell clone* ■ antibody secretion (primary immune response) ■ development of immunological memory *Part of clonal selection

Macrophage interaction with neutralized or agglutinated (antibody-bound) pathogen

Source:	Signal:	Response/Recipient Cell:
Macrophage	**Antibody**	**Macrophage activation** ■ phagocytosis of pathogen

Macrophage interaction with Ab-precipitated soluble antigen

Source:	Signal:	Response/Recipient Cell:
Macrophage	**Antibody**	■ macrophage activation ■ phagocytosis of antigen
Mast cell	**Histamine**	■ inflammatory response ■ chemotaxis ■ recruitment of phagocytes

Part III – Communication between two neurons OR between a neuron and a muscle cell

Neuron-to-neuron transmittance of an action potential via neurotransmitter release at chemical synapse

Source:	Signal:	Response/Recipient Cell:
Pre-synaptic neuron	**Neurotransmitter**	■ binding to postsynaptic membrane ■ opening or closing of ion channels in postsynaptic membrane (chemical gating) ■ change in membrane potential in postsynaptic membrane (graded potential; may be EPSP, IPSP, or both) ■ depolarization or hyperpolarization (opening or closing of ion channels) of postsynaptic membrane ■ possible action potential in postsynaptic cell ■ rapid enzymatic degradation of neurotransmitter ■ spatial summation (multiple presynaptic neurons stimulating a postsynaptic neuron simultaneously) ■ temporal summation (a single presynaptic neuron stimulating a postsynaptic neuron in rapid-fire sequence)

Pre-gap neuron to-post-gap neuron transmittance of an action potential via gap junctions (electrical synapses)

Source:	Signal:	Response/Recipient Cell:
Pre-synaptic neuron	**Current flow**	■ rapid depolarization of postsynaptic neuron ■ maintenance of signal strength ■ synchronization of vertebrate neuronal responses

Release of acetylcholine at neuromuscular junction

Source:	Signal:	Response/Recipient Cell:
Pre-synaptic neuron	**Acetylcholine**	■ depolarization of muscle fiber plasma membrane ■ action potential carries to T-tubules ■ Ca^{++} release from sarcoplasmic reticulum ■ Ca^{++} binding to troponin ■ conformational change of tropomyosin ■ exposure of myosin binding sites ■ cross-bridge formation ■ muscle fiber contraction ■ cholinesterase termination of response

Note: An accurate description of events at a neuromuscular junction involving cardiac muscle or smooth muscle can earn up to 4 points in this category.

Note: Components of a reflex arc may be described under either neuron-to-neuron communication, or neuron-to-muscle cell communication. However, a portion of the reflex arc must be isolated and described on the basis of two individual cells communicating, viz., either one neuron with another neuron, or a neuron with a muscle fiber.

Part IV – Endocrine-gland-cell to target-tissue-cell communication

Hypothalamic/Posterior Pituitary Hormones

Source:	Signal:	Response/Recipient Cell:
Hypothalamic/Posterior Pituitary Hormones	**ADH (vasopressin)**	■ second messenger, e.g., cAMP ■ increased water reabsorption by collecting duct ■ urine concentration/osmoregulation ■ vasoconstriction increases BP
Hypothalamic/Posterior Pituitary Hormones	**Oxytocin**	■ increased uterine contraction ■ increased milk ejection/letdown

Addendum, *continued*

Hypothalamic Hormones

Source:	Signal:	Response/Recipient Cell:
Hypothalamus	**Releasing hormone**	■ increased hormone secretion by anterior pituitary (adenohypophysis) ■ second messenger, e.g., cAMP ■ see specific anterior pituitary hormones for additional effects
Hypothalamus	**Inhibiting hormone**	■ decreased hormone secretion by anterior pituitary ■ see specific anterior pituitary hormones for additional effects

(Anterior) Pituitary Tropic Hormones

Source:	Signal:	Response/Recipient Cell:
Anterior pituitary	**FSH**	■ increased follicular growth (granulosa cells) ■ increased estrogen release by growing follicle ■ second messenger, e.g., cAMP ■ negative feedback of further FSH and LH release by estrogen ■ increased sperm production in males (Sertoli cells)
Anterior pituitary	**LH (ICSH in males)**	■ increased follicular maturation ■ ovulation ■ promotes formation/maintenance of corpus luteum ■ increased gonadal steroid secretion by ovaries/testes ■ second messenger, e.g., cAMP
Anterior pituitary	**TSH (thyrotropin)**	■ increased hormone production/secretion by thyroid ■ increased thyroid growth ■ second messenger, e.g., cAMP
Anterior pituitary	**ACTH**	■ increased release of adrenal steroids ■ second messenger, e.g., cAMP
Anterior pituitary	**Growth hormone (STH)**	■ growth stimulation (bone/muscle) ■ increased protein synthesis ■ alters metabolism

(Anterior) Pituitary Nontropic Hormones

Anterior pituitary	**Prolactin**	■ increased mammary gland growth/maturation ■ increased milk production/synthesis ■ increased nest building ■ decreased LH secretion in males
Anterior pituitary	**MSH**	■ stimulation of melanocytes ■ second messenger, e.g., cAMP

Thyroid Hormones

Source:	Signal:	Response/Recipient Cell:
Thyroid	**Triiodothyronine/ thyroxine (T3/T4)**	■ metabolic stimulation required for development/growth
Thyroid	**Calcitonin**	■ increased bone formation ■ decreased blood calcium/maintenance of homeostasis ■ second messenger, e.g., cAMP

Parathyroid Hormone

Source:	Signal:	Response/Recipient Cell:
Parathyroid glands	**Parathyroid hormone (PTH)**	■ increased blood calcium/maintenance of homeostasis ■ increased calcium reabsorption by kidneys ■ increased calcium absorption by GI tract ■ second messenger, e.g., cAMP

Pancreatic Hormones

Source:	Signal:	Response/Recipient Cell:
Pancreas	**Insulin**	■ maintenance of blood glucose uptake/metabolism ■ increased glucose conversion to glycogen
Pancreas	**Glucagon**	■ increased glycogen breakdown to glucose ■ second messenger, e.g., cAMP
Pancreas	**Somatostatin**	■ inhibition of insulin and glucagon release ■ decreased digestive tract activity

Adrenal (Medulla) Hormones

Source:	Signal:	Response/Recipient Cell:
Adrenal medulla	**(Nor)epinephrine**	■ glycogen breakdown ■ increased blood pressure ■ increased breathing rate ■ increased metabolic rate ■ fight or flight → changes in blood distribution ■ second messenger, e.g., cAMP

Adrenal (Cortex) Hormones

Source:	Signal:	Response/Recipient Cell:
Adrenal cortex	**Glucocorticoid** (cortisol)	■ increased protein/fat conversion to glucose ■ increased blood glucose ■ immune system suppression ■ suppression of inflammation
Adrenal cortex	**Mineralocorticoid** (aldosterone)	■ increased water reabsorption by kidney ■ increased Na^+ reabsorption by kidney ■ increased excretion of K^+ ■ maintenance of mineral (electrolytes) homeostasis
Adrenal cortex	**Sex hormones**	See androgens and estrogens below

Gastrointestinal Hormones

Source:	Signal:	Response/Recipient Cell:
Stomach	**Gastrin**	■ increased food digestion by stomach
Small intestine	**Secretin**	■ increased HCO_3- secretion by pancreas
Small intestine	**Cholecystokinin**	■ release of pancreatic enzymes ■ increased gall bladder contractions
Small intestine	**Enterogastrone**	■ alters intestinal segmentation

Pineal Gland Hormone

Source:	Signal:	Response/Recipient Cell:
Pineal Gland	**Melatonin**	■ regulation of circadian rhythms ■ control of puberty onset

Addendum, *continued*

Gonadal Hormones

Source:	Signal:	Response/Recipient Cell:
Testes	**Androgens**	■ maintenance of male sexual behavior ■ male secondary sex characteristics ■ sperm production
Ovaries	**Estrogens**	■ maintenance of female sexual behavior ■ female secondary sex characteristics ■ growth of uterine lining ■ mammary gland growth/differentiation
Ovaries	**Progesterone**	■ growth of uterine lining ■ mammary gland growth/differentiation

Kidney and Liver Hormones

Source:	Signal:	Response/Recipient Cell:
Kidney/Liver	**Renin/Angiotensin II system**	■ angiotensinogen → angiotensin I → angiotensin II ■ increased thirst ■ increased vasoconstriction ■ increased aldosterone
Kidney	**Erythropoietin**	■ increased erythropoiesis ■ increased O_2-carrying capacity of blood
Kidney	**Vitamin D (calcitriol)**	■ increased uptake of Ca^{++} by gut

Thymus Hormone

Source:	Signal:	Response/Recipient Cell:
Thymus	**Thymosin**	■ increased T-lymphocyte activity

Embryonic Hormone

Source:	Signal:	Response/Recipient Cell:
Embryo	**Human Chorionic Gonadotropin (HCG)**	■ maintenance of estrogen secretion by corpus luteum ■ maintenance of progesterone secretion by corpus luteum

Note: An accurate description of an endocrine gland, hormone, and responses from an invertebrate organism can earn up to four (4) points in this category.

Note: An accurate description of the basis for specificity in the binding of a particular hormone to its target cell will earn a response point.

Sample Student Responses for Free-Response Question 2

Essay 1 (7 points)

Neurons communicate through the events which occur at synaptic vessicles. When a presynaptic cell is stimulated by the nerve impulse, voltage gated protein channels open in the cell's membrane and allow for the influx of Ca^{2+} ions. This in turn causes the packaging of synaptic vesicles by the Golgi body. These vessicles pass across the synapse and onto the postsynaptic cell. The neurotransmitters of these molecules lead to receptor mediated response by the post-synap cell. They fit into specific receptors of this cell and cause for the vesicles to be carried into this cell. By therefore transporting its ionic contents to the new cell it ~~carries out the ic~~ creates a concentration gradient which propogates the nerve impulse. Thus, the impulse from the dendrite of a neuron is carried across the synapse and if sufficient ~~it is~~ (meeting the threshold requirement) the nerve impulse is continued

The anterior pituitary gland produces a hormone known as TSH - thyroid stimulating hormone. This tropin molecule stimulates the ~~produc~~ the thyroid to produce thyroxin which in turn increas metabolic activities within the body. Through a negative feedback the brain is able to sense the levels of metabolic activity throughout the body. When these levels are too high it decreases the production of TSH

and thus reduces metabolic levels.

Immune-system cells communicate through receptor mediated endocytosis. As antibodies are produced they bind with the receptor proteins in the membrane of other immune cells. It causes endocytosis to occur and the material is then transported into the cell.

Commentary on Essay 1

Points were earned as follows: a **source** point for identifying the pre-synaptic neuron, a **signal** point for a generic neurotransmitter, a **response** point for neurotransmitter binding at the post-synaptic membrane, a **source** point for the pituitary, a **signal** point for TSH, a **response** point for thyroxin production by the thyroid, and an **elaboration** point for a description of feedback control.

Essay 3 (10 points)

Communication between two immune-system cells is achieved through binding or releasing chemicals For example, a viruses infected cell can act as a antigen presenting cell and put a piece of the epitope on its cell membrane (combined with a class one MHC protein). When ~~kills~~ a partially activated killer T cell (Tc cell) comes, it binds to the virus, infected cell and ~~is~~ completes its activation. Also, when macrophage is activated during humoral immune responce, it releases ~~interferon~~ interlukin 1 to signal ~~the~~ ~~T~~ helper T cells.

The results of those communications are:

1. The activation of ~~cel~~ certain immune cells in order to destroy the antigen
2. To enable ~~the~~ cells like ~~#~~ Tc cells to ~~recogg~~ recognize the antigen.

Communication between two neurons is when they conduct a nerve impulse. When a nerve impulse arrives at the presynaptic membrane, the membrane ~~is~~ becomes permeable to Ca^{2+} so Ca^{2+} ions diffuses into the terminal knob and activate ~~microtu~~ microfillaments inside that can creat current to draw synaptic vesicles close to the membrane. Then, the synaptic vesicles ~~are~~ fuse with the membrane, releasing neurotransmitters into the synaptic clift. Neurotransmitters diffuse across the synaptic clift and bind to receptors on the post synaptic membrane causing Na^+ gates to open. If enough Na^+ gates open to reach the membrane

threshold, a nerve impulse will be conducted by the second neuron.

~~Commuta~~ Communication between a endocrine-gland cell and its target cell is achieved through chemicals (hormones). When sensory receptors are stimulated, they send impulses to the control center which direct the adaptive responses. ~~If~~ Endocrine glands can be the effectors. When a endocrine gland is stimulated, the cells produce ~~or rele~~ and/or release hormones. If the hormone is made of proteins, it will bind to ~~a~~ receptors on the target cell ~~on~~ and will activate a series of enzyme catalysed reactions to cause changes in its metabolic rate. If the hormone is a steroid, it will pass through the cell membrane of the target cell, bind to receptors in the cytoplasm and with the receptor enters the nucleus causing changes in gene expression.

The types of responses that result from this communication depend on types of the endocrine gland cell and its target cell. For example, thyroxin produced by thyroid gland cause an increase in metabolic rate in the target cell. Follicle Stimulating Hormone produced by anterior pituitary cause the follicles in ovaries to develop. (in female of course).

Commentary on Essay 3

Points were earned as follows: a **source** point for antigen presentation; a **signal** point for T_C-APC binding; a **response** point for the completion of T_C activation; a **response** point for T_H recruitment; a **source** point for the pre-synaptic neuron; a **signal** point for a generic neurotransmitter; a **response** point for the opening of Na^+ channels in the post-synaptic membrane; a **response** point for steroid vs. non-steroid pathways, a **signal** point for thyroxin; and a **source** point for the thyroid.

Common Errors and Misconceptions

Answers often incorporated vague phrases such as "cells talking to each other," "messages traveling along pathways," "signals sent and received," etc., without any mechanistic explanation of how any of this occurred. Many students wrote of cell membrane receptors while rarely linking these receptors to a signal coming from another cell; reflecting an imprecise reading of the question.

Plant Communication

- Students often were unable to associate a response to the hormone that elicits it.
- Many students wrote (for no credit) of communication between guard cells and stomates, between source cells and sink cells, and between xylem cells.

Immune-System Communication

- Students were unable to sort out the complexity of what cells interact with what other cells.
- General statements of "B cells talking to T cells," "antibodies protecting the body against disease," and "the immune system's ability to distinguish self from non-self" were frequent.
- Many students wrote of an immune-system cell interacting with a virus or bacterium without relating this response to a signal from another immune system cell.

Neuron-to-Neuron Communication

- While students often were able to describe the idea of a sending cell and the idea of a neurotransmitter, their descriptions of events in the postsynaptic neuron were lacking in specificity.
- Statements such as "the neuron gets the message" were common.
- Students often stated incorrectly that an action potential originates at an axon, travels through the cell body, and terminates at a dendrite, where it is transmitted to the next neuron.
- Many students described the propagation of an action potential within a neuron but wrote nothing about signal transmission between two neurons.

Neuron-to-Muscle Cell Communication

- Students often stated that "the muscle contracts", and context made clear that they were referring to the entire muscle (e.g., gastrocnemius) rather than an individual muscle fiber.
- Rarely did students describe events associated with the sliding filament theory.
- In the papers that had a reflex arc as an example, students usually referred to the arc as a single entity and concluded with a statement of how one pulls one's hand away from a hot object as a response. Rarely did students isolate two individual cells (neuron–neuron or neuron–muscle fiber) and explain events in terms of cell-to-cell communication.

Endocrine Communication

- Students often were unable to link an endocrine gland correctly to a hormone from that gland, although they were more often able to link a hormone correctly to its appropriate effects.
- Understanding of the action of steroid vs. nonsteroid hormones was lacking.

Question 3 is a three-part question that begins with a stem describing a classification system based on a taxonomic category called the domain. This classification system is different from the Five-Kingdom system that is currently taught to most biology students. Students were asked to **describe** how this new classification scheme is different from the five-kingdom system; **describe and explain** how three kinds of evidence were used to develop the new scheme; and finally, **describe** four characteristics of a universal ancestor. To receive full credit, students had to answer all three parts, but points were distributed in the following way:

- Section I - 4 points
- Section II - 6 points
- Section III - 4 points

A maximum of 9 points could be earned for Sections I and II or Sections II and III. Students could receive a score of 10 only by answering all three sections of the question.

Section I could be answered by students who knew the five-kingdom system, and could interpret the diagram provided in the question. Section II required students to know something about Eubacteria, Archaebacteria, and Eukaryotes. Section III required students to understand that a universal ancestor probably had characteristics common to all three domains. Students were awarded only 1 point in Section III for a *list* of characteristics of the universal ancestor; full credit required a description of the characteristics. Since Section II asked how evidence was used to develop the taxonomic scheme, not for comparison with the five-kingdom system of classification, any differences among the domains were accepted. Also, Section II asked for three kinds of evidence. As indicated in the directions printed on the back of the pink booklet, only the first three characteristics that a student described were graded, even though many students wrote on more than three.

For full credit, a student must receive at least 1 point from each section.

Section I

Maximum of 4 points from this section

For Section I, the guidelines included a list of six possible conclusions (each worth 1 point) about relationships among organisms that could be drawn from the classification scheme presented. These conclusions showed this classification scheme to be different from the five-kingdom system. Another point could have been earned by listing the five kingdoms from the earlier classification system.

(1) Not all prokaryotes are closely related (not monophyletic).
(1) Prokaryotes split early in the history of living things (not all in one lineage).
(1) Archaea are more closely related to Eukarya than to Bacteria.
(1) Eukarya are not directly related to Eubacteria.
(1) There was a common ancestor for all extant organisms (monophyletic).
(1) Eukaryotes are more closely related to each other (than Prokaryotes are to each other)
(1) Correct description of the five-kingdom system.

Section II

Maximum of 6 points, 3 points from the first three descriptions of evidence mentioned and 3 from the explanations. The explanations must differentiate between at least two of the groups.

Part II asked for three descriptions of kinds of evidence that were used to develop the new classification scheme. The students then had to go further and explain how the evidence was used. It was expected that in this part differences among the three domains would be described. Each difference mentioned was worth 1 point. The explanations should indicate which group had which characteristic. In order to get the explanation point, students had to compare at least two of the three groups. The guidelines for this section list 28 possible different kinds of evidence that the students might describe and explain in order to get points on this section.

Descriptions	**Explanations**		
Differences	Eukaryotes	Archaea	Eubacteria
Habitat — mostly extreme (halophilic, thermophilic, acidic)	–	+	–
Reproduction	Mitosis/meiosis	Binary fission	Binary fission
Multicellularity exists	+	–	–
Nucleus	+	–	–
Membrane-bound organelles	+	–	-
Microtubules/ microfilaments	+	–	–
Cell walls with peptidoglycan	–	–	+
Chromosomes: Shape Number Histones present	 Linear More than one +	 Circular One +	 Circular One –
Ribosomes: Size Base sequence of rRNA	 Large Similar	 Small Similar	 Small Unique
Structure of tRNA	Similar	Unique	Similar
RNA polymerase	Multiple types	Multiple types	Single type
Introns	Present	Some	None
Operon organization of genes	–	+	–
Initiator amino acid in protein formation	Methionine	Methionine	Formyl-methionine
Phospholipids: Bonds Hydrocarbon structure		 Ether Branched	 Ester Unbranched
Can be pathogens	+	–	–
Response to antibiotics such as streptomycin or chloramphenicol	–	–	+
Response to diphtheria toxins	+	–	–
Metabolism Can be methanogens Enzymatic make-up differs Enzyme location differs Photosynthetic pigments differ	 – Must correctly describe what the difference is.	 +	 –
Differences in gene sequences of DNA	Must correctly describe what the difference is.		
Differences in whole genome sequences	Must correctly describe what the difference is.		

Section III

Maximum of 4 points for this section. Described characteristics can earn 1 point each OR 1 point may be earned for a list of the first four correct characteristics. The question asked for descriptions, but it was decided that just listing the four characteristics correctly without describing them would earn 1 point.

Characteristic (possible explanations)

(1) Small (surface to volume ratio, no internal transport system)
(1) Unicellular (all functions self-contained)
(1) Prokaryote (no membrane-bound organelles).
(1) Had cell membrane (containment, protection, semipermeable)
(1) Had cell membrane made of a phospholipid bilayer (barrier).
(1) Had cytoplasm (different from external environment)
(1) Had DNA for the genetic material (**or** nucleic acid **or** RNA)
(1) Had mRNA for information transfer (common to all organisms)
(1) Had tRNA to carry amino acids and/or aminoacylsynthetase (common to all organisms)
(1) Had ability to reproduce (asexual)
(1) Had ability to mutate, adapt, or evolve through natural selection
(1) Had ability to make proteins or had ribosomes on which proteins could be constructed
(1) Had metabolism: carbon-based or organic; Energy transformations, ATP as energy molecule
(1) Had enzymes for amino acid, nucleotide, and coenzyme synthesis as well as enzymes for glycolysis and the Krebs cycle (common to all organisms)
(1) Heterotrophic/autotrophic* with explanation
(1) Anaerobic/aerobic with explanation
(1) Aquatic with explanation

Because Part II asked for six pieces of information ("**describe** 3 . . . and **explain**. . . ."), and Part III asked for a description of four characteristics, a maximum of 4 points were attainable for parts I and III and 6 points were attainable for part II. It was necessary to answer each part of the question in order to get full credit; a maximum of 9 points were awarded for either parts I and II or II and III.

*not photosynthetic

Essay 2 (8 points)

• The system of Domains is different in that it does not group Bacteria and Archae bacteria together as the five Kingdom system did. It is also different in that the evolutionary lines appear to be different. The archaeBacteria were thought to be ancestors of the bacteria domain but from this diagram they are along the lines of the Eukaryotes while the bacteria have a separate line. The Kingdom classification is concerned more with the division of Eukaryotes than the divison of types of cells.

• The ~~evidence~~ evidence used to create the taxonomic scheme can come from the actual structure of the organisms. Mitochondria in eukaryotes is thought to have been descended from the archaebacteria called Purple sulfer bacteria and thus they are grouped together. ~~Photosynthet~~ Bacteria did not use chemiosynthesis and utilized other methods such as photosynthesis to obtain energy. To separate Eukaryotes from archaebacteria and eubacteria, the chromosome structure was used as well. The ~~chromosomes~~ DNA in eubacteria and archaebacteria is circular and bound to the cell membrane. The bacterias both only contain one ~~chromosome~~ circle of DNA. The Eukaryotes contain several chromasomes worth of DNA. The method of replication is thus different as well, the two Domains of bacteria replicate by binary Fission while eucaryotic cells go through mitosis to replicate.

• The universal ancestor must have had a cell membrane which includes a phospholipid bilayer. This provides for exchange of chemicals with the environment and protects the organism.

• This universal ancestor must have used DNA as ~~a method of [illegible]~~ genetic information. The DNA codes for proteins which are needed ~~to~~ in the function of an organism.

• It must have had some method of acquiring energy with ATP. The ATP fuels the other processes in the cell.

• It must have had some method of protein synthesis with ribosomes ~~and RNA, in~~ ~~so that the bacteria~~ because proteins are required for ~~ma~~ cellular functions.

Commentary on Essay 2

This student was able to interpret the cladogram and also had the knowledge necessary to explain it. In Part I the student earned 2 points, one by explaining that the prokaryotes (group Bacteria and Archaebacteria) are not monophyletic, and 2 by showing that the Archaebacteria are more closely related to the Eukaryotes than to the Eubacteria.

In Part II the student earned credit for saying that there are differences in chromosome number in the bacteria and Eukaryotes, then explaining that the eubacteria and archaebacteria have a single chromosome while the eukaryotes have several chromosomes. Unfortunately, the student began the paragraph with an attempt to give two pieces of evidence that were not correct, so the reader, who assigns points only to the *first three* items mentioned, was not able to give points to the evidence of reproduction differences the student mentioned at the end of the paragraph.

In Part III the student earned the maximum number of points possible (4) and even had further correct information. Two points were earned for (1) describing the cell membrane and its function, (2) stating that the cell membrane is a phospholipid bilayer and further explaining the functions. Two more points were earned for explaining that (1) DNA would be the genetic material and the (2) DNA coded for proteins.

Essay 3 (10 points)

This classification scheme differs in that the old one lumped Archebacteria and eubacteria into a single kingdom, labled Monera. These bacteria were considered simply prokaryotes.

Prok Kingdom eukaryotic Kingdoms — all others.
↓
monera (Archae and eubacteria)

The conclusions are different for the following reasons. Placing the archaebacteria as a branch off the eukaryotic domain implies that it is more closely related to the eukaryotic stock than eubacterial stock. Secondly, placing this differance in a higher taxon implies that the kingdom grouping of bacteria is inadequate. Not only are archaebacteria and eubacteria not close enough to be in the same kingdom, they are in different domains. Thirdly this system acknowleges that eukaryotes are an inclusive taxon and it places them not as simply offshoots of bacteria, but as a divergent strain from a common ancestor with archaebacteria.

The first evidence that archaebacteria are not to be grouped with eubacteria is that they have a different membrane and cell wall composition. They lack layers of peptidoglycan that eubacteria have. This characteristic is closer to eukaryotes. Secondly, Archebacteria are

accustomed to extreme conditions that eubacteria are not. They can be extreme halophiles, living in extreme salt, or thermoacidophiles that live in extremely hot or acidic environments, and they can live as methanogens in the guts of animals, neither of which a eubacteria is capable of. Thirdly eukaryotes are divided from the other 2 domains because they have different ribosomes, an endomembrane system, different methods of gene regulation and protein production and different cell wall make up if any.

A characteristic of the universal ancestor would be the presence of ribosomes to produce proteins. Second would be the presence of DNA as genetic material for protein codes. Third would be the existance of a phospholipid bilayer as a plasma membrane. And fourth would be glycolysis as a means of extracting energy from glucose into ATP.

Commentary on Essay 3

This is a superior paper. In Part I, the student clearly explained that the diagram separated the Archaebacteria and Eubacteria into two domains and put the Archaebacteria in a closer relationship to the Eukaryotes. Furthermore, he/she mentioned that the Eukaryotes are inclusive. Three points were earned.

In Part II, the student earned 2 points by citing differences in cell wall composition as evidence for separation of the Eubacteria from other domains. The student further explained that the difference in cell wall composition is due to the presence of peptidoglycan in the Eubacteria and its absence in the other domains. The second 2 points were earned by his/her discussion of habitat differences between the Archaea and Eukaryotes and Bacteria. Finally 2 points were earned by the discussion of metabolism differences in Archaebacteria from Eukaryotes and Bacteria demonstrated by the production of methane by some Archaebacteria.

In Part III, the student gave an excellent description of four characteristics of the universal ancestor, all or which were correct. The student could have earned 4 points. The whole question has a maximum of 10 points which the student more than earned!

Common Errors and Misconceptions

Many students seemed:

- to be unfamiliar with the term "domain" (it is not prominent in the textbooks) even though it was not necessary to have known about domains to earn a good score on the question;
- to be unable to read the cladogram;
- not to understand the major differences between Eukarya and Bacteria;
- confused about cyanobacteria and protists.

The stem of question 4 describes three criteria of hereditary material (precise copying, stable but able to change, complex enough to determine phenotype). Students are asked to explain how DNA meets these criteria. After selecting one of the criteria, students have to describe the evidence from experiments that supports knowledge that DNA is the hereditary material.

The standards for the first part of the question focusing on how DNA meets the three criteria listed in the question were fairly straightforward, with many opportunities to garner points. The second part of the question was more complicated in that the question asked more than just describing an experiment that showed that DNA was the genetic material. The question asks students to link their chosen experiment to one of the criteria listed in the stem. For this question, the first part requires more information than the second does, so the point values were split 8 to 2 between the two parts.

Note: Part A can earn a maximum of 8 points. Part B can earn a maximum of 2 points.

A. Explain how DNA meets each of the three criteria stated above [8 points maximum]

1. Molecular Properties for Precise COPYING [3 points maximum]

- Template concept (semi-conservative replication)
- Molecular structure (e.g., complementary base pairing; A:T,C:G; purine-pyrimidine pairing; antiparallel)
- DNA polymerase function in copying
- Separation concept
- Elaboration of replication (e.g., specific roles of other replication enzymes, proper sequence of steps)

How students could earn points in this section:
Points were awarded in this section for correctly linking structure or other molecular properties of DNA to the copying mechanism. One point could also be awarded for a description of the copying process without an accompanying explanation linking the steps to molecular properties. A point could also be earned for explaining the role of DNA polymerase.

2. Molecular Properties that make it STABLE but ABLE to change [3 points maximum]

Stable

- Energetically favorable arrangement; stable because of shape of molecule (e.g., double helix; bases in the interior of the helix)
- Energetically favorable arrangement; stable because of bonding (e.g., multiple H bonds; phosphodiester bonds)
- Silent errors (e.g., "junk" DNA; introns; redundancy of the genetic code)
- Able to be repaired (e.g., proofreading)

Able

- Description of a mutation (e.g., substitution; deletion; insertion; inversion; translocation)
- Crossing over (e.g., during meiosis)
- Base changes (e.g., depurination; deamination; tautomerism)
- Gene rearrangements (e.g., antibody genes in stem cells; transposons)
- Sensitive to mutagens (e.g., UV; X-ray)
- Restriction enzyme recognition sequences

Stable or Able (with justification)

- Methylation
- Telomeres protect ends

> **How students could earn points in this section:**
> In this section students could earn points for discussing the properties that make DNA stable and for discussing the points that make DNA able to be changed. The student could earn the maximum by addressing either or both aspects of this criterion. No points were awarded for general description of the molecule unless the student specifically linked the description to the ability to remain stable or be able to change. (Students often described the molecule, e.g., *double helix, H bonds between the bases,* without demonstrating any understanding that these properties contribute to stability and/or changeability.) For the same reason, a point for the mutation concept was not awarded unless the student described a type of mutation, showing how mutation changes the molecule, e.g., *during replication the molecule can change because it is possible for it to experience a base substitution,* rather than *DNA can change by mutation.*
> The latter seems to say DNA can change by changing. Two properties included in the standards could arguably provide either stability or changeability. Either explanation was acceptable with justification.

3. Molecular Properties that make it COMPLEX enough to determine PHENOTYPE [3 points maximum]

   - Colinearity of gene and protein (i.e., base sequence determines aa sequence)
   - Infinite base sequence combinations lead to protein variety
   - Variable numbers of base pairs per gene lead to different sizes of polypeptides
   - Proteins are responsible for phenotype
   - Description of transcription and translation
   - Chromosome structure as it relates to function (e.g., supercoiling; chromosome or gene inactivation; interaction with histones; etc.)

> **How students could earn points in this section:**
> Points were awarded for describing the properties of the molecule that make it complex enough to determine phenotype. One point could be awarded for a description of transcription and translation without an accompanying explanation linking the steps to molecular properties.

B. Select one of the criteria stated above and describe experimental evidence used to determine that DNA is the hereditary material [2 points maximum]

- Identification of experiment with valid link to any one of the criteria [1 point maximum]:
  1) precise copying
  2) stable but able to change
  3) complex enough to determine phenotype
  4) DNA is the hereditary material
- May include but need not be limited to experiments that show:
  - DNA can transform bacteria
  - viral DNA can reprogram cells
  - equivalence of A:T and C:G
  - double helix structure, (e.g., x-ray crystallography)
  - replication is semiconservative

- hereditary enzyme deficiency disorders have genetic links
- DNA codes for protein
- changes in DNA quantities during the cell cycle (mitosis/meiosis)
- chromosome markers linked to disorders
- measurement of mutation rates
- changes in DNA (biotechnology)

■ Description of EVIDENCE [1 point maximum]
Evidence provided in the context of an experiment

How students could earn points in this section:
One point was awarded for correctly identifying an experiment that provided evidence for the criterion chosen by the student. If more than one criterion was selected, the reader scored the first one chosen. The readers treated *"that DNA is the hereditary material"* as a fourth criterion. Therefore, even though only three criteria were actually enumerated in the question, the students could choose an experiment that provided evidence for this implied fourth criterion. While not every experiment cited was familiar to the readers, every experiment cited was judged according to whether it could reasonably provide the evidence described. The second point was awarded for describing the evidence in the context of an experiment.

Sample Student Responses for Free-Response Question 4

Essay 1 (10 points)

DNA replicates itself using semiconservative replication. This means that each parent strand of DNA will serve as the template for forming a new DNA molecule, resulting in daughter molecules that are 1/2 old DNA and 1/2 new. The DNA molecule is split down the middle by helicase, which breaks the bonds holding the complementary nucleotides together. Helicase functions in a 3' to 5' direction, while the next step, synthesis, occurs in a 5' to 3' direction, with 3' and 5' denoting the ends of the DNA molecule. A new strand is synthesized by DNA polymerase, which catalyzes the adding of new nucleotides to each half of the DNA molecule. Thus, each daughter DNA molecule is identical to its parent, ~~because of the process it became upon~~

The DNA molecule is held together in the middle by hydrogen bonds between the 2 strands, and nucleotides are attached to one another lengthwise down the molecule by phosphodiester bonds. Both of these bonds, plus the coiling of the molecule, contribute to its stability. However, variation is possible due to mutations in the DNA. Mutations may be caused by a number of sources, but they all include the changing of the sequence of nucleotides. ~~Nucl~~ Nucleotides may be inserted into the chain, deleted, or translocated. Each of these mutations corresponds to a change in the structure of the protein that the gene codes for, which may or may not have serious effects.

DNA consists of 4 nucleotides — adenine, guanine, cytosine, + thymine. Adenine & guanine are purines, and have complementary structures to cytosine + thymine, which are pyrimidines (A pairs with T, + C pairs with G) These four nucleotides, arranged in various sequences along a molecule of DNA are responsible for the incredible diversity of proteins that may be produced. Nucleotides code for proteins in triplets, or codons. Each amino acid corresponds to several

different codons. (64 codons are possible, and 20 amino acids exist, with 2 codons signalling for "stop") The phenotype of an organism is a result of the variations in the proteins produced in this way.

Messelson & Stahl performed an experiment to prove Watson & Crick's theory of semiconservative replication of the DNA molecule. They used a centrifuge to separate DNA from bacteria. The DNA formed a band visible in the tube. When the bacteria were grown in a medium containing heavy nitrogen isotope (^{15}N), the band was in a different place. When they allowed the bacteria to grow in the medium long enough for 1 generation of replication, the band formed was between the 2 light & heavy bands, suggesting that it consisted of 1/2 light & 1/2 heavy DNA. One more replication in a ^{14}N medium would result in only light & medium bands, showing that half of the strands were all new DNA, while the other half were hybrid light & heavy. This proved that each time, half of the DNA served as a template for replication of a new half of the molecule.

Commentary on Essay 1

This paper earned a 10 and was very concisely written. On part A(1) the student earned the maximum 3 points; one for describing the template concept, one for describing the DNA separation concept, and one for describing the role of DNA polymerase in copying. The student actually addressed all 5 points listed in the standards. On part A(2) the maximum 3 points were again awarded, one for explaining that the shape of the molecule contributes to its stability, one for explaining that hydrogen bonds contribute to the stability, and one for explaining that insertions, deletions, and tranlocations change the DNA molecule. Two points were awarded for part A(3), one for explaining that many base sequences are possible and one for explaining that proteins are responsible for phenotype. In part B both points were earned, one for correctly linking an experiment to the "copy" criterion and one for describing the essential design of, and the experimental evidence derived from, the Meselson and Stahl experiment.

Essay 3 (6 points)

DNA meets each of the criteria because it can copy itself through the process of DNA replication in which each half of the DNA strand serves as a template for a new complementary strand (semiconservative). It also ~~has~~ includes structures such as DNA ligase and helicase which check and fix DNA errors (along with DNA polymerase). The arrangement of hydrogen bonds, phosphates, and nitrogenous bases contribute to its stability. And the varying sequences of the bases allow DNA to be complex enough to determine an organism's phenotype. The order of the bases dictate which amino-acids are produced therefore determing which phenotype is expressed.

To determine that DNA was in fact the hereditary material used to determine the organism's phenotype, a few scientists used bacteriophages incorporated with ^{32}P and ^{27}S. Mixing a bacteria culture with the bacteriophages, the scientists were able to determine whether DNA was the hereditary material by tracing the movement of of the isotopes (^{32}P and ^{27}S). The ^{32}P was ~~ab~~ incorporated into the bacteriophage's DNA while the ^{32}S combined with another cellular organelle. From the new colonies, produced by the infected bacteria, only ^{32}P was present indicating that the DNA from the "parent" bacteria colony was replicated and produced in the "daughter" bacteria colony. Therefore, DNA had to be the genetic material.

Commentary on Essay 3

Although the essay includes several errors, it still conveys a general sense of understanding the subject. In part A(1) the student earned 1 point for understanding the template concept but did not provide any specific details to earn the other points. In part A(2) the student earned 2 points for describing both the hydrogen bonding property and proofreading to explain stability. In part A(3) the student earned 1 point for linking base arrangement to phenotype. For part B the student chose the "DNA is the genetic material" criterion. He/she earned 1 point for identifying an appropriate experiment and 1 point for describing the evidence in the context of the experiment.

Common Errors and Misconceptions

Students know many facts about DNA structure, replication, transcription, and translation. Some of the things we have learned from the responses are that many students:

- know that the two chains of the double helix are complementary but don't understand why that is significant
- know that there are hydrogen bonds between the complementary base pairs but don't understand why that is significant
- understand the relationship of mutation to DNA structure
- know a lot of technical vocabulary terms but are very confused about how the details they have learned fit together coherently
- know structure, but are generally weak on process, or why structure is important
- do not understand what constitutes experimental evidence
- do not distinguish between evidence and conclusions drawn from evidence
- understand the relationship between genes and proteins
- do not understand the relationship between DNA, RNA, nucleotides, amino acids, and proteins
- do not understand that gene expression *is* phenotype
- do not know the difference between replication and transcription

Table 4.2 — Scoring Worksheet

Section I: Multiple Choice

[________ − (1/4 × ________)] × .7563 = ________ = ________

Number correct (out of 119) — Number wrong — Multiple-Choice Score — Weighted Section I Score

Section II: Free Response

Question 1 ________ (out of 10) × 1.500 = ________

Question 2 ________ (out of 10) × 1.500 = ________

Question 3 ________ (out of 10) × 1.500 = ________

Question 4 ________ (out of 10) × 1.500 = ________

Sum = ________

Weighted Section II Score

Composite Score

________ + ________ = ________

Weighted Section I Score — Weighted Section II Score — Composite Score (Round to nearest whole number.)

AP Grade Conversion Chart
Biology 1999

Composite Score Range*	AP Grade
86-150	5
66-85	4
48-65	3
29-47	2
0-28	1

*The candidates' scores are weighted according to formulas determined in advance each year by the Development Committee to yield raw composite scores; the Chief Faculty Consultant is responsible for converting composite scores to the 5-point AP scale.